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The basic autonomous profiler development is complete and now has a track record of more than one-year successful field operation. The performance of the Argos data link has been characterized to determine the expected throughput and error structure and a report prepared. Similarly historical temperature and salinity profiles have been characterized with respect to the properties affecting data compression schemes. Combining characteristics of the Argos system and the signal, a basic methodology for formatting data transmissions has been developed, programed for a controller and tested. After a survey of the performance and cost of available instrumentation it has been decided that sound speed profiles are best determined by measuring temperature and conductivity from which sound speed is computed.

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4.3 (U) Technical Status and Issues

(U) The basic autonomous profiler development is complete and now has a track record of more than one-year successful field operation. The performance of the Argos data link has been characterized to determine the expected throughput and error structure and a report prepared. Similarly historical temperature and salinity profiles have been characterized with respect to the properties affecting data compression schemes. Combining characteristics of the Argos system and the signal, a basic methodology for formatting data transmissions has been developed, programmed for a controller and tested. After a survey of the performance and cost of available instrumentation it has been decided that sound speed profiles are best determined by measuring temperature and conductivity from which sound speed is computed.

(U) The primary short-term technical issue remains selection and/or development of the best conductivity sensor for long-term applications. Field tests have disclosed weaknesses in the first sensor candidate but reaffirmed the wisdom of computing sound speed from conductivity and temperature. Emphasis in the current year is on short-term testing and multiple calibration of candidate sensors and long-term field testing of the stability of the best sensor.

(U) In the longer run the main issue is reducing the cost of fielding such instruments both by minimizing their production costs and simplifying deployment, perhaps even to making an air-deployable repetitive temperature profiler.

4.4 (U) Planned Work

(U) FY92: Tests carried out in FY91 show our first sensor choice was a poor one. Preliminary tests of an early version of the newly-developed Falmouth Scientific Instruments inductive sensor show promise and this will be thoroughly tested in FY91. Plans for FY92 are based on the assumption that these tests of the FSI sensor will prove it to be suitable. In FY92 we will (a) place one of the two prototype instruments under long-term testing either near San Diego or in conjunction with the ONR Subduction Experiment; (b) monitor the results of the long-term test; (c) prepare a technical report on our various sensor tests; and (d) use a second prototype profiler to transfer the developed technology to NOARL.

These activities will be completed by March 1992 using funds provided in April 1991.

4.6 (U) Potential Problem Areas in Planned Work

(U) On the short term, the process of transition will be more successful if there are NOARL personnel available to participate in selecting a suitable performance test and to observe instrument preparations and deployment.

(U) On the long term, the success of this and other autonomous instruments depends on a a satellite data relay system of adequate throughput and suited to use by instruments with limited onboard power. In present instruments more energy is spent communicating with Argos than is used in all other functions including vertical profiling.

4.7 (U) Summarv of Current Year's Work (FY91)

(U) Seven uninstrumented profilers have completed 15 months of operation cycling to 750 m depth twice per month having transitted from Drake Passage into a braod area of the southwestern South Atlantic; a seventh failed in its eleventh month of operation. Data transmission is reliable and depth reproducibility satisfactory. Numerous design weaknesses of the basic profiler have been uncovered and design corrections made.

(U) One prototype profiler was constructed as a test vehicle for an inexpensive Ocean Sensors conductivity-temperature-depth (CTD). Repetitive laboratory calibration and local field tests indicated that the sensor calibration was subject to abrupt shifts corresponding to salinity variations of the order 0.1 PSU or sound speed variations of 0.2 m/s. While marginally adequate for the design objective of 0.25 m/s accuracy, this leaves little margin for degradation over long-term deployments. Further, it indicated that the Ocean Sensors conductivity cell (which was optimized for spatial resolution) is not the best choice for long-term use where stability is the primary measure of quality.

Recently we took delivery of a newly-developed inductive conductivity sensor built by Falmouth Scientific Instruments. This sensor has two significant theoretical advantages over four-electrode cells such as the Ocean Sensors sensor. First, there are no electrodes in contact with seawater and degradation or changes of the electrode surface are one likely source of loss of sensor stability. Second, the inductive cell samples a much larger volume than available electrode conductivity cells. Small particles (primarily of biological origin) cause significant changes of cell constant if they obstruct the physically small constrictions used to make electrode cells sensitive. The very much larger inductive cell should be significantly less affected by these tiny perturbations.

A second profiler was manufactured and the FSI sensor mounted along with the inexpensive temperature and pressure sensors used in standard ALACE floats. Preliminary field tests with this instrument show the FSI sensor is indeed stable but more testing and repetitive calibration are needed before we will be sufficiently confident to begin a long-term (months) field test. These tests are planned for the remainder of the current (FY91) year.

4.8 (U) Projected Accomplishments for Execution Year (FY92)

Early in FY92 one of the two prototype profilers will be deployed for a long-term test, probably in the ONR Subduction Experiment in the eastern North Atlantic. Our various laboratory and field tests with Ocean Sensors and Falmouth Scientific Instruments sensors as well as preliminary results from this long-term test will be described in a technical report prepared at the end of FY92. The second prototype profiler, which by then will be retrofitted to have the most promising sensor suite, will serve as the basis for transitioning the developed technology to NOARL. We intend to plan a demonstration test in concert with NOARL personnel and to use this operation both to demonstrate the instruments' performance and to pass along lessons in operating it.

Ed Mozley: On the time-line diagram I would like to extend the Select Sound Speed or Conductivity Sensor line through FY91 to end with a Complete & Report.

NOARL (ONR) N00014-89-C-6014

AUTONOMOUS OCEAN PROFILER

Trimester Report — February 1991 through May 1991

Seven of the current-following Autonomous Lagrangian Circulation Explorers (ALACEs) moving through the South Atlantic were still operational at the end of April 1991, having completed 15 months of operation and 30 vertical cycles to 750 m. The design life is 25 months and 50 cyles. The eighth instrument failed after 25 cycles, having reported on its last cycle a sudden 300 m increase of depth. After substantial laboratory testing we have discovered a weakness in the mechanical design such that after many pressure cycles a glued joint is subject to fatigue which leads to a high pressure leak. A fix has been introduced into new floats but the remaining seven South Atlantic floats are subject to this failure.

Previously a prototype profiler was constructed and fitted with a lightweight Ocean Sensors CTD. Repetitive laboratory calibration and local field tests indicated that the sensor calibration was subject to abrupt shifts corresponding to salinity variations of the order 0.1 PSU or sound speed variations of 0.2 m/s. While marginally adequate for the design objective of 0.25 m/s accuracy, this leaves little margin for degradation over long-term deployments. Further, it indicated that the Ocean Sensors conductivity cell (which was optimized for spatial resolution) is not the best choice for long-term use where stability is the primary measure of quality.

During this trimester construction of a second profiler was completed except for the temperature sensor, which temporarily is a rather too slow thermistor probe used with ALACE temperature profilers. This was fitted with a Falmouth Scientific Instruments (FSI) inductive conductivty sensor, a recently developed new product. This sensor theoretically has two significant advantages over four-electrode conductivity cells such as the Ocean Sensors sensor. First, there are no electrodes in contact with seawater and degradation or changes of the electrode surface are one likely source of loss of sensor stability. Second, the inductive cell samples a much larger volume than available electrode conductivity cells. Small particles (primarily of biological origin) cause significant changes of cell constant if they obstruct the physically small constrictions used to make electrode cells sensitive. The very much larger inductive cell should be significantly less affected by these tiny perturbations.

The power consumption of the FSI sensor delivered to us was about twice what the manufacturer had anticipated. It can be reduced to about half by changing some of the instrumentation quality operational amplifiers. Nevertheless, power use by the present conductivity sensor to measure a profile is less than half that needed to relay that data through Argos.

The field test completed this trimester involved both prototype profilers, one with the Ocean Sensors CTD and the other with the Falmouth Scientific Instruments conductivity sensor and available temperature and depth sensors recorded by the standard ALACE controller. Figure 1 shows salinity vs. temperature traces from two cycles to 350 meters depth. The comparison is marred by apparent malfunctions of the Ocean Sensors temperature sensor, which showed high-

frequency noise and apparent calibration shifts, and absence of a full calibration of the Falmouth Scientific sensor (it is being calibrated now). Nevertheless it is clear that (a) the Ocean Sensors profiles are much less reproducible than those from the Falmouth Scientific Instruments sensor and (b) the variability observed with the FSI sensor is small, comparable to what other workers in the area have reported as the result of lateral intrusions ubiquitous in the area. There is an offset between the instruments which we suspect is the result of the Ocean Sensors calibration shift observed in the last field test. Figure 2 shows the departure of inferred sound speed from that computed using a fixed salinity of 33.4 PSU. Even the Ocean Sensors instrument which is clearly inferior allows sound speed to be computed within an error of about 0.2 m/s. The FSI variability is nearer 0.1 m/s.

Fig 1

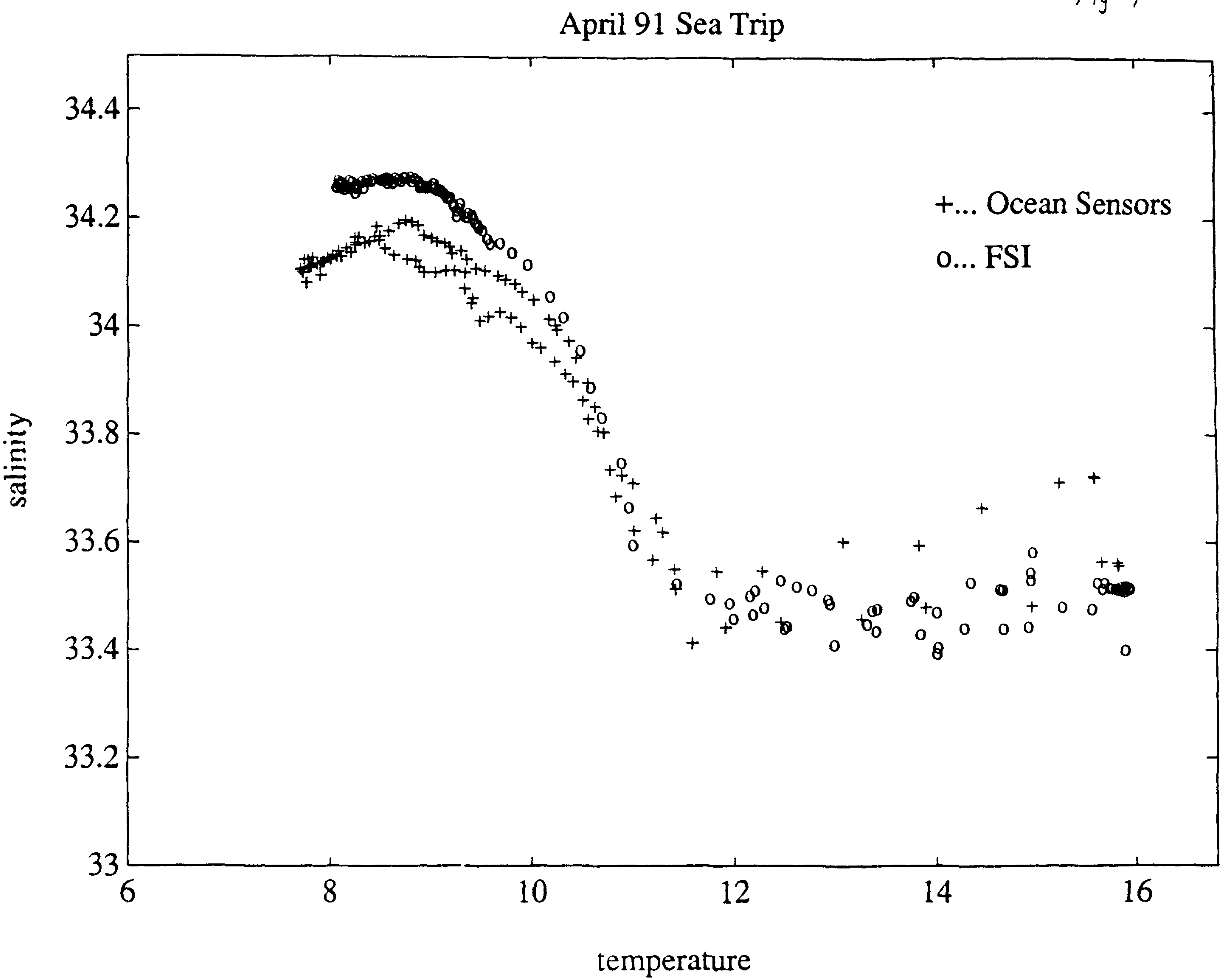
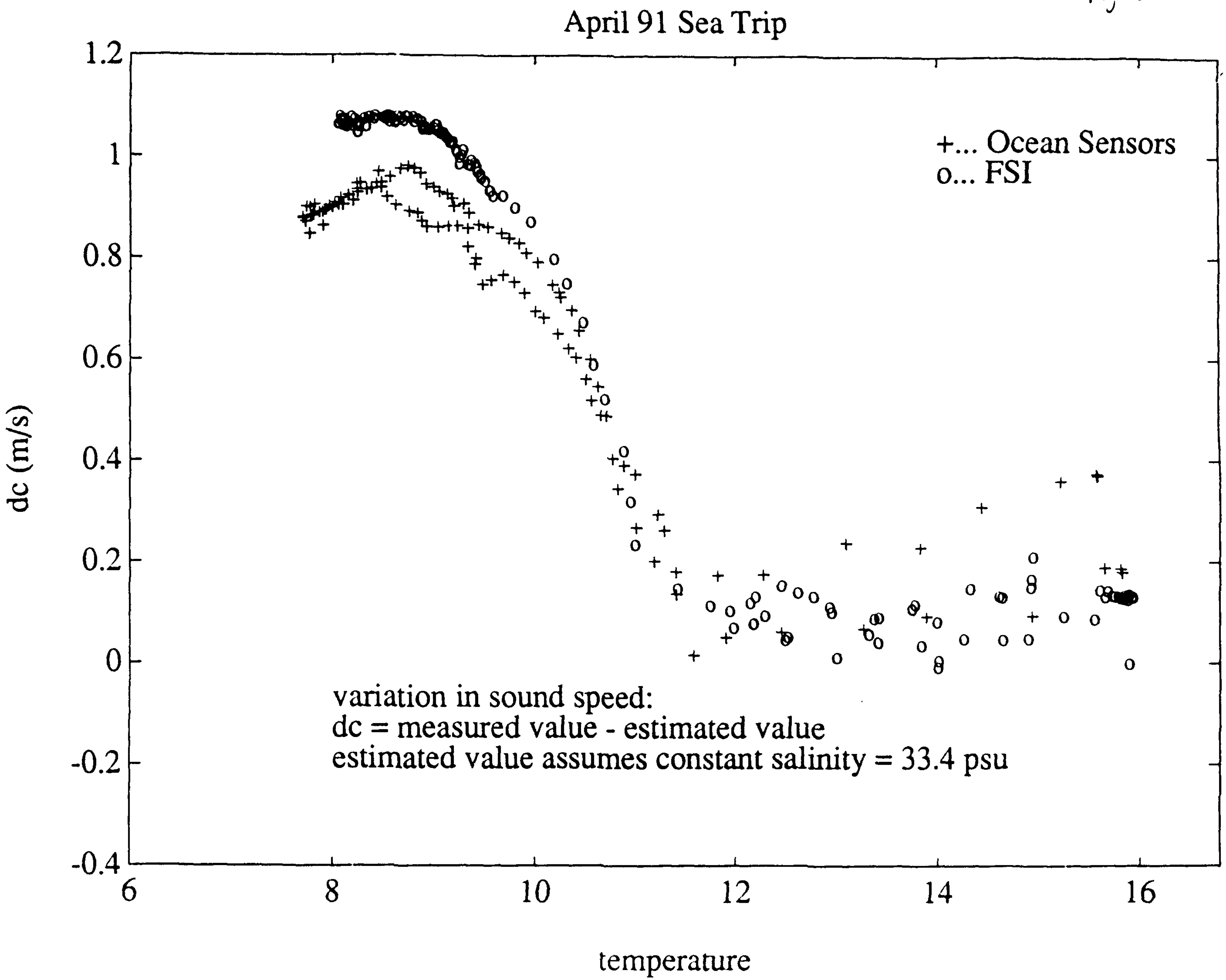

April 91 Sea Trip
+... Ocean Sensors
o... FSI
salinity
34.4
34.2
34
33.8
33.6
33.4
33.2
33
6
8
10
12
14
16
temperature

Fig 2


April 91 Sea Trip
+... Ocean Sensors
o... FSI
variation in sound speed:
dc = measured value - estimated value
estimated value assumes constant salinity = 33.4 psu
dc (m/s)
temperature
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
6
8
10
12
14
16

NOARL (ONR) N00014-89-C-6014

AUTONOMOUS OCEAN PROFILER

Annual Report — April 1990 through May 1991

The autonomous ocean profiler is a vertically cycling instrument for gathering ocean profile data over long periods of time and relaying it through the Argos satellite system which also locates the buoys. The objective of the present program is to develop a profiler capable of reporting sound speed profiles with an accuracy of 0.25 m/s over many months of operation and order 50 cycles. It is based on the ALACE float which is an uninstrumented float used to measure subsurface currents through observed displacement between successive surfacings.

Progress during this year has been made in three basic areas: (a) improvement of the basic profiling float and buoyancy controller; (b) data handling, including analysis of the throughput and errors of the Argos system and development of a suitable data compression scheme for profile data; and (c) selection and testing of sensors for measuring conductivity, temperature and pressure from which sound speed can be calculated.

In April 1991, seven basic ALACE floats completed their 15th month of operation moving through the South Atlantic after deployment in Drake Passage during January 1990 having completed 30 cycles to 750 m. The design life is 50 cyles which will be reached in January 1992. The eighth instrument failed after 25 cycles, suffering what we believe was a mechanical failure introduced by cyclic fatigue. Since these floats were deployed, we have isolated and eliminated numerous design errors including potential vapor lock of the hydraulic pump which caused many failures of the original model and the mechanical fatigue which we suspect caused the eigth Drake Passage float to fail. The basic profiler is now reasonably reliable, but both these problems caused delays in the field testing part of the program.

The profiler depends on the Argos satellite system to locate the observations and to relay the profile data. The Argos system has a very limited throughput (a few hundred bytes per day) and the electrical energy needed to relay a hundred bytes is comparable to that needed to carry out a vertical profile. The relayed data is also subject to a fairly high error rate and, because of the random access nature of the transmission protocol, some messages are received many times while others are not received. Consequently an effective data transmission scheme is essential to reliable relay of the profile data and to obtaining long operational life.

As a prelude to designing a data compression scheme, the throughput and error structures of the Argos system were examined using a long series of transmissions for a land site. These showed that the last bit in a long message is much more error prone than the first bit. They also showed that the errors in received messages caused relatively insignificant data loss compared with the loss of whole messages that were simply not received. The implication for transmission strategies is that error-correcting codes will be inefficient because the error runs are long (complete transmissions are lost). Thus the most efficient relay strategy is repeated retransmission of all data and structuring data messages so that loss of one complete transmission does not destroy

the entire information content of the set of messages. The results of this analysis have been submitted for publication by the Journal of Atmospheric and Oceanic Technology.

A data compression scheme has been designed and tested on sample profiles gathered by other instruments. The scheme consists of the following steps: (a) Both the temperature and salinity profiles are split into two parts, putting successive measurements in alternate parts; each of these four parts forms a complete Argos message so that even if one message is lost a complete profile will be available, albeit at reduced spatial resolution. (b) The mixed layer depth and temperature and five temperatures at predetermined depths below the mixed layer are sent with full resolution (typically 9 bits); these define straight-line segments approximating the profile. (c) Departures from the straight lines in each segment are sent using only five bits encoded on a nonlinear scale so that small (expected) departures have greater resolution than larger (exceptional) departures. A typical profile might then be sent in less than one day providing unambiguous ranges and resolution as follows (depth ranges are based on a mixed layer depth of 50 meters).

Range (m)	Depth (m)	Temperature (°C)	Salinity (psu)	Sound Speed (m/s)
0-250	5	1.8 (0.06)	1.8 (0.06)	7.0 (0.24)
260-450	10	0.9 (0.03)	0.9 (0.03)	3.5 (0.12)
470-1030	20	0.6 (0.02)	0.6 (0.02)	2.4 (0.08)

This has been tested on data gathered by a number of different conductivity and temperature sensors in various locations.

The profiler and data transmission are useless without sensors which can adequately measure sound speed over long periods. Early in this project it was decided to compute sound speed from measured temperature and conductivity rather than to measure sound speed directly. The desired 0.25 m/s accuracy over long periods of time is beyond the capability of inexpensive sound speed sensors and accurate ones are prohibitively expensive. On the other hand, conductivity accuracy corresponding to 0.1 PSU salinity error (which is within the advertised capabilities of inexpensive conductivity sensors) corresponds to sound speed accuracy of better than 0.25 m/s. Further, a conductivty-temperature-depth instrument will be mcuh more generally useful than one which measures sound speed.

The first sensor examined was an Ocean Sensors lightweight CTD. It was tested for time response and salinity spiking in our laboratory drop tank. The response was found to be surprisingly sensitive to the orientation of the sensor with respect to the oncoming flow. This information was used to design an appropriate fixture for mounting the sensor on the first prototype profiler. The sensor was subjected to repetitive laboratory calibrations and found stable.

The first field trial of this profiler was carried out in local waters during December 1990. It consisted of three vertical cycles to 420 m depth over the span of a few hours. Sensor performance was disappointing although marginally adequate for a sound-speed accuracy of 0.25 m/s. After almost two cycles in which the T-S curve was well repeated, the conductivity calibration appeared to jump irreversibly by an amount equivalent to a salinity change of 0.1 PSU. We believe that this calibration shift was the result of a small particle, probably biological, sticking

to the conductivity sensor and altering the cell constant. The Ocean Sensors probe uses a very small probe optimized for sensitivity to fluctuations which are small in both physical size and conductivity change. In retrospect we should have suspected that the sensor would be susceptable to such particles so that in the present application, where stability is the primary goal, a more appropriate sensor might have been selected.

We have purchased one of the first new inductive conductivity sensors developed by Falmouth Scientific Instruments (FSI) which is the new home of Neil Brown. This sensor was developed with the specific goal of achieving high accuracy without frequent recalibration. This sensor theoretically has two significant advantages over four-electrode conductivity cells such as the Ocean Sensors sensor. First, there are no electrodes in contact with seawater so degradation or changes of the electrode surface are eliminated as a source of instability. Second, the inductive cell samples a much larger volume than do available electrode conductivity cells. Small particles (primarily of biological origin) can cause significant changes of cell constant if they obstruct the physically small constrictions used to make electrode cells sensitive. The very much larger inductive cell should be significantly less affected by these tiny perturbations.

A second prototype profiler was constructed using the FSI conductivity sensor. Tests of this new sensor are still quite preliminary but are promising. In a recent field comparison of the two protoype profilers, one using the Ocean Sensors CTD and the other using the FSI conductivity sensor, it was clear that the FSI sensor was more repeatable and subject to none of the apparent shifts in calibration observed with the small four-electrode probe. Repeated calibrations and another local field test are planned for both profilers and a long term deployment is scheduled for the beginning of the next fiscal year but hopes are high that the FSI sensor will provide stable profile measurements, useful not only for sound speed profiling but in other studies where temperature and salinity profiles can be used to diagnose ocean dynamics.